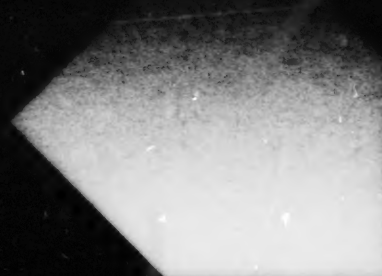
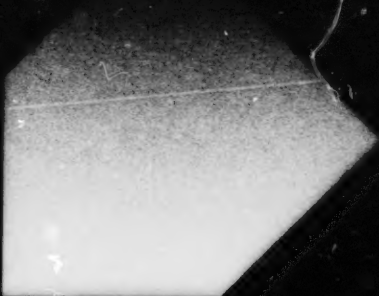


Canada Mortgage
and Housing
Corporation



Société canadienne
d'hypothèques et
de logement



CMHC

CONTROL OF SUBSURFACE MOISTURE:

**REPORT
ON THE USE OF
SAND-BENTONITE
BACKFILL**

Prepared for

**Project Implementation Division
Policy, Research and Programs
Canada Mortgage and Housing
Corporation**

by

**GE Ground Engineering Ltd
Regina, Saskatchewan**

December 1987

**Principal Consultants:
Paul Kozicki**

**CMHC Project Managers:
Terry Robinson**

REPRINT - CMHC 1987

Canada Mortgage and Housing Corporation, the Federal Government's housing agency, is responsible for administering the National Housing Act.

This legislation is designed to aid in the improvement of housing and living conditions in Canada. As a result, the Corporation has interests in all aspects of housing and urban growth and development.

Under Part V of this Act, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research. CMHC therefore has a statutory responsibility to make widely available, information which may be useful in the improvement of housing and living conditions.

This publication is one of the many items of information published by CMHC with the assistance of federal funds.

DISCLAIMER

This study was conducted by GE Ground Engineering Ltd for Canada Mortgage and Housing Corporation under Part V of the National Housing Act. The analysis, interpretations and recommendations are those of the consultants and do not necessarily reflect the views of Canada Mortgage and Housing Corporation or those divisions of the Corporation that assisted in the study and its publication.

CMHC SUMMARY

Background:

Swelling/shrinking clay soils, particularly common in many parts of Western Canada, have often caused foundation problems due to excessive soil pressures on basement walls and uplift pressures on basement slabs. It has been proposed that the use of an impervious backfill, such as a sand-bentonite mixture, will prevent such problems by reducing soil pressures and water infiltration around basements.

Objectives:

To determine the effectiveness of sand-bentonite in reducing soil pressures and water penetration around basements.

Methodology:

The Consultant installed a new concrete foundation on bored piles under an existing dwelling being renovated in Regina. A suspended wood floor was used in place of a conventional basement slab, and sand-bentonite backfill was used in place of native clays. The perimeter drain tile system was eliminated. Soil pressures, backfill settlement and soil moisture profiles were monitored over a one year period.

Conclusions:

The Consultant's findings indicated that the sand-bentonite backfill maintained relatively dry subsoil conditions adjacent the basement wall, although the report states that soil moisture contents may eventually increase over a period of years as equilibrium is reached.

In comparison to typical clay backfill, the sand-bentonite performed significantly better, with less than half the lateral earth pressures developed and virtually no settlement.

Higher moisture contents were found at the base of the wall, indicating that water was able to bypass the sand-bentonite through cracks in the undisturbed native clay. This underscored the need for a suspended basement floor to prevent uplift problems.

The costs for the bored piles, higher concrete walls, suspended floor, sand-bentonite backfill, engineering fees and the elimination of the drainage tile resulted in an increase of approximately \$3000 over conventional practices.

Recommendations:

Based on the study's findings, the Consultant recommends the use of an "engineered foundation package" for problem clay sites. This includes bored pile supports, a suspended wood floor, and sand-bentonite backfill.

REPORT ON THE USE OF SAND-BENTONITE BACKFILL TO REDUCE
SOIL PRESSURES AND WATER INFILTRATION AROUND UNDERGROUND
BASEMENT WALLS

PAUL KOZICKI, P. ENG.
WALTER BUETTNER, P. ENG.
GE GROUND ENGINEERING LTD.
REGINA, SASKATCHEWAN

EXECUTIVE SUMMARY

A field research study on the use of sand-bentonite backfill to reduce soil pressures and surface water infiltration around underground basement walls in an area with shrink/swell clay soils was carried out by GE Ground Engineering Ltd. under a Contract Agreement with Canada Mortgage and Housing Corporation, dated October 10, 1986. The house building in this study was supported on a bored type pile foundation system. The basement floor was constructed as a suspended wood floor system. The conventional perimeter weeping tile drainage system was eliminated and the local clay backfill against the basement walls was replaced using a mixture of sand and 20 percent bentonite.

The objectives of the field research study included providing and installing instrumentation to monitor subsurface conditions for a period of approximately one year. The data obtained was analyzed and observations were made to determine the effectiveness of the system in reducing soil pressures and preventing moisture accumulation near basement walls. The results of the field research study showed conclusively that a sand-bentonite backfill material does effectively reduce the infiltration of surface drainage into the subsoils surrounding the basement and minimize lateral earth pressures on underground basement walls.

The incremental costs to a home builder for substituting the sand-bentonite backfill for conventional backfill, and for substituting the suspended wood floor for a conventional grade supported basement floor slab were determined to be \$3,053.00 for the house building involved in this study.

Some of the information included in the discussion and comments are made on the basis of thirty (30) years of field observation and foundation engineering experience of the writers with numerous buildings supported on different type foundation systems in an area (Regina, Saskatchewan) with shrink/swell type clay soils.

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SECTION 1.0 BACKGROUND AND OBJECTIVES OF STUDY

Shrink/swell clay soils are common in many areas of Western Canada, and can result in basement slab heaving and cracking. Excessive soil pressures can also be exerted on foundation walls and can cause serious structural damage to housing. The damage to houses and light structures in areas of shrink/swell soils starts occurring shortly after construction. The results have been cracked walls, heaved slabs, disjointed utility lines, jammed doors and similar engineering or construction failures. These miserable features have become so prevalent to be almost accepted by owners as inevitable and defying solution at reasonable cost. Such problems lower property values and can result in high costs to homeowners for repair work.

This attitude is wrong, and most of those involved in foundation engineering know this to be so. Nevertheless, for a variety of reasons, improvements in planning, design and construction are not being implemented with the speed and thoroughness that the state-of-the-art warrants. The problems associated with differential movements of shallow foundations in shrink/swell clay soils has been the subject of much research. Pertinent literature and references are included appended to this report. Researchers have provided current knowledge to designers, designers have passed it on to builders, builders have consulted with financiers and regulatory agencies, but still the

owners and users end up with the problems of old.

The current practice of placing clay soils in large chunks and in an uncompacted state against house basements and other shallow retaining walls is widespread because of a lack of a more desirable backfill soil. When placed in this manner, the backfill material is relatively permeable to water infiltration, and the total forces exerted on underground walls often exceed the structural strength of lightly reinforced and immature concrete basement walls. The breakdown and settlement of this chunky backfill is a cause of maintenance problems for many years after construction. The consolidation and later swelling due to moisture change with time of this material, and the addition of fill to restore original grade, can ultimately increase pressures against basement walls beyond earth pressures assumed in design.

In areas with shrink/swell clay soils, it is important to minimize the infiltration of water into the foundation soils. The conventional approach to handling water infiltration around foundations is to install a perimeter weeping tile drainage system around the outside of the perimeter footings connected to an interior sump or sewer located in the basement area. While this method is relatively successful at controlling the perched water table around the exterior foundation walls, it does not prevent, and in most cases dramatically contributes to the increase in the moisture regime of the foundation soils beneath the floor slab. As the soil moisture regime increases the clay subsoils expand causing the basement floor slabs to heave.

GE Ground Engineering Ltd. has proposed the use of a sand-bentonite mixture as a backfill material which will effectively reduce the infiltration of surface drainage into the subsoils surrounding the foundations and minimize lateral earth pressures on underground basement walls. Also, the use of an impervious backfill material will control the increase in the soil moisture regime of the foundation soils beneath the building structure. Bentonite is a natural occurring clay which absorbs water and forms a seal against further water penetration. Bentonite has been used successfully in a variety of forms as a sealant and water seepage control barrier. Bentonite was first used as waterproofing as early as 1925, but is not widely known in building and

residential fields. The bentonite can be admixed with low quality fine grained sand and used as a backfill material around underground structures and in service trenches to provide a barrier for seepage control and water impedance. Dry sand-bentonite is very easily compacted.

In Canada there are presently two companies producing bentonite products. One plant is located at Wilcox, Saskatchewan and is operated by Avonlea Mineral Industries Ltd. The other plant is located in Rosslind, Alberta and is operated by M-1 Drilling Fluids Canada Inc.

The use of suspended wood floors rather than poured concrete slabs also represents an additional measure which will avoid the destructive effects associated with heaving subsoils. The basement floor system is suspended by the foundation walls and supported at mid-span on a bored pile and spandrel grade beam type foundation system. The ground surface beneath the basement floor is covered with a vapor barrier and a minimum 300mm space is provided beneath the floor joists and the ground surface. Services lines and heat ducts are installed beneath the floor system.

The objective of this field research project was to determine the effectiveness of the sand-bentonite backfill material in reducing water infiltration around underground basements and minimizing lateral earth pressures on these walls.

A residential building located at 198 Angus Crescent in Regina, Saskatchewan, was selected for this study. It underwent complete renovations in 1986. These renovations consisted of replacement of the existing basement with a new basement of poured concrete construction. The new basement was supported on a bored type pile foundation system. The basement floor was constructed as a suspended wood floor system. In addition, the new basement was designed without the conventional perimeter weeping tile drainage system and sump to collect surface water infiltration. The local clay backfill against the basement walls was replaced with a lightly compacted sand-bentonite mixture. During 1987 the house building was not equipped with eavestroughs to collect the roof drainage. All the roof drainage during this period was allowed to fall on the backfill material around the perimeter of the building. To

provide information on the effectiveness of the sand-bentonite mixture in controlling the surface infiltration of water and minimizing lateral earth pressure, a monitoring system was installed to measure lateral soil pressures on the underground basement walls and changes in the subsoil moisture regime. As well, the incremental costs of a bored pile foundation and suspended wood floor system as compared to the conventional shallow spread footing and grade supported concrete floor system were determined.

SECTION 2.0 MONITORING PROCEDURES AND INSTRUMENTATION

A site plan and cross section of the residential house building located at 198 Angus Crescent in Regina, Saskatchewan, is shown in Figures 1 and 2. These figures indicate the details of the pile foundation and structural floor system as well as the locations and types of monitoring equipment installed.

Monitoring equipment was installed on October 10, 1986, at two locations around the basement wall and consisted of a Total Earth Pressure Cell, Model TP-101 manufactured by R.S. Technical Instrument Ltd., and a settlement plate installed at shallow depth in the sand-bentonite backfill. In addition, the moisture content of the sand-bentonite backfill was measured by test drilling and obtaining representative samples at specific depths. It was originally intended to determine soil moisture profile by using a Nuclear Depth Moisture Gauge. Access tubes were installed and attempts were made to record the moisture profile; however, due to damage to the tubes, the nuclear probe could not be used. Photographs of the monitoring equipment installed and specification sheets on the Total Earth Pressure Cell are shown in Appendix A. A standpipe piezometer was installed in the southeast corner of the basement area. The standpipe piezometer consisted of 100mm slotted plastic pipe installed to a depth of 1.2 metres below the bottom of the basement excavation.

Laboratory and field testing was conducted on the sand-bentonite mixture used as backfill around the basement excavation. This testing indicated that the sand-bentonite mixture contained approximately 20 percent bentonite and 80 percent silty sand. A grain size curve of the sand-bentonite mixture is shown

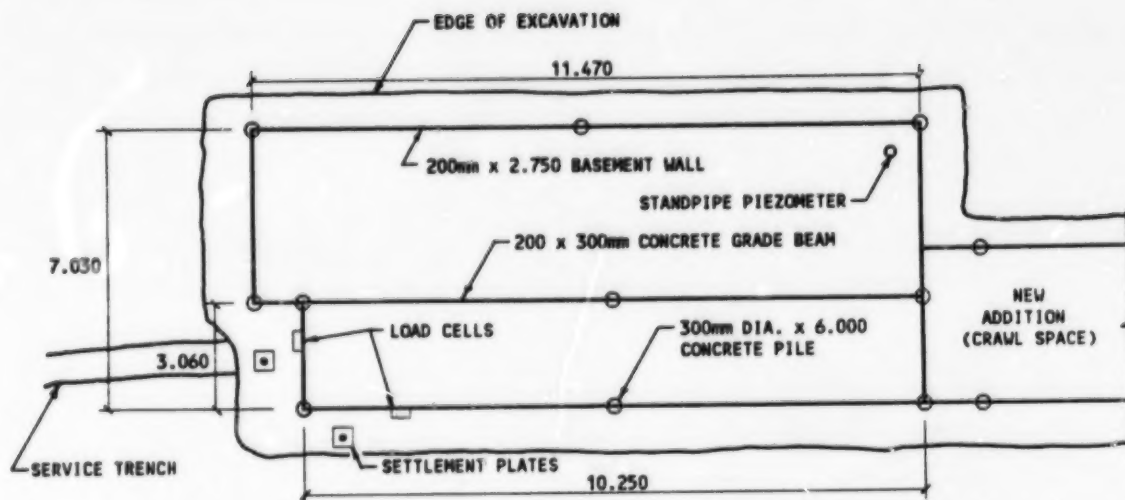


FIGURE 1 - PLAN VIEW OF BASEMENT

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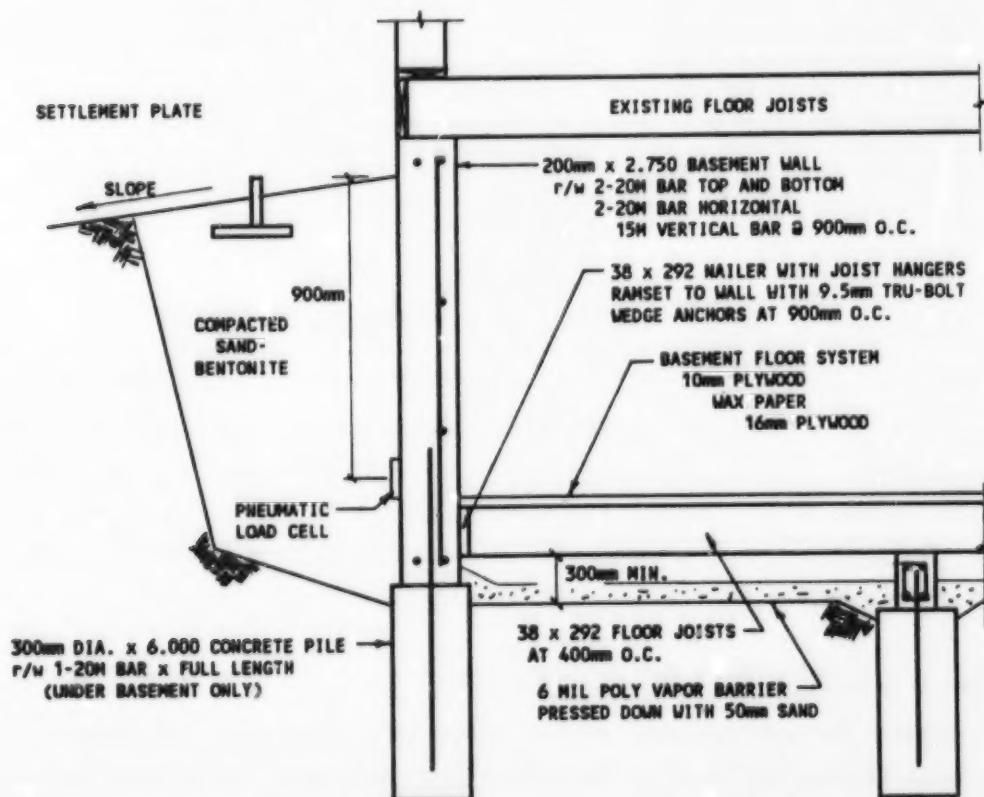


FIGURE 2 - CROSS-SECTION THROUGH BASEMENT WALL

NOT TO SCALE

in Figure 3. The in-place density of the backfill at the time of compaction varied from 0.99 to 1.26 tonnes/cubic metre with an average density of 1.17 tonnes/cubic metre. The moisture content of the sand-bentonite mixture varied from 8.0 to 9.6 percent, with an average of 9.4 percent.

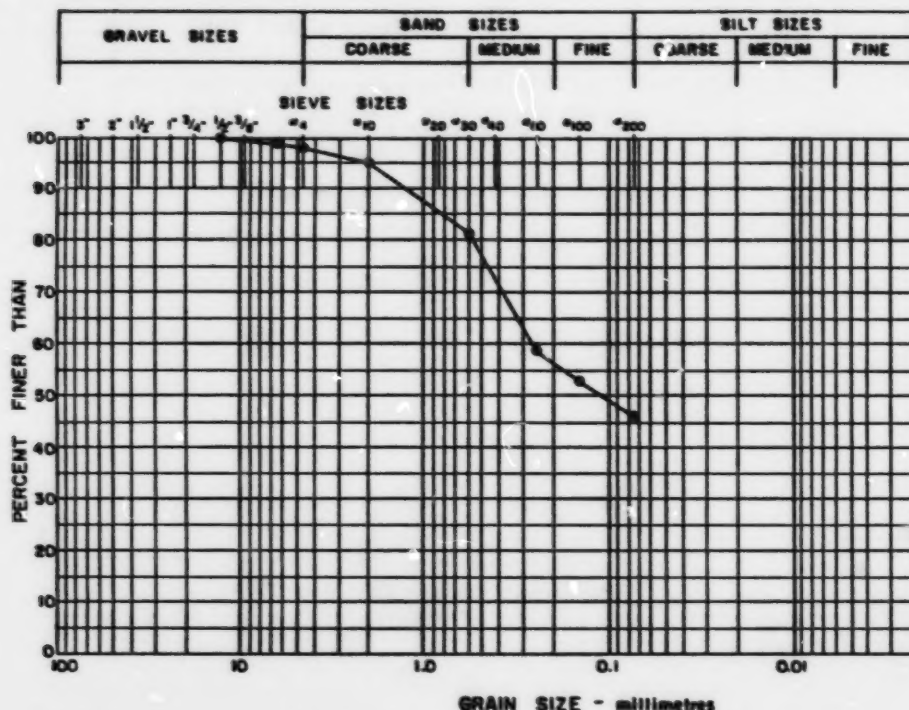


FIGURE 3 - GRAIN SIZE ANALYSIS OF SAND-BENTONITE MIXTURE

After the initial 500mm of sand-bentonite backfill material had been placed around the basement excavation, a period of rainfall occurred and a 500mm depth of water ponded on top of the sand-bentonite mixture for a 2 to 3 week period. This water was allowed to slowly evaporate before placing the remainder of the sand-bentonite backfill. During this period no water seepage was observed in the bottom of the basement excavation.

SECTION 3.0 ANALYSIS OF MONITORING DATA

Monitoring results from the total earth cells are presented in Figure 4. Included in this figure are monthly precipitations and mean daily temperatures for Regina as compiled by Environment Canada. Figure 4 indicates that lateral earth pressures are slowly increasing with the maximum recorded pressure of 2 kPa.

Piezometer monitoring data indicated that it remained completely dry during the fall and winter period. During the spring period, with the total rainfall of about 130mm, the highest water level recorded in the piezometer was measured at 150mm below the ground surface elevation in the bottom of the basement excavation. The water level in the piezometer dropped during the summer and fall period until the piezometer became dry in September. It is anticipated that the piezometer should remain permanently dry now that the eavestrough system has been installed to collect the roof drainage and the landscaping has been completed to provide positive drainage of surface water away from the building.

The results of moisture content testing is shown in Figure 5. These results indicate the surface and bottom of the sand-bentonite backfill has increased in moisture content to the 18 to 32 percent range. The moisture content of the insitu clay is in the range of 22 to 27 percent. However, the centre of the backfill at the depth of the total earth pressure cells (i.e. 900mm) has increased in moisture content only 1 to 3 percent. The explanation for the relatively dry condition of the sand-bentonite at the centre of the backfill is that as water infiltrates the sand-bentonite backfill material, the bentonite expands in volume and the hydraulic conductivity of the backfill material decreases. This can be demonstrated in a simple test by placing a sample of dry sand-bentonite mixture in a glass jar and pouring water on top of the sample. The relatively high moisture content values obtained for the sand-bentonite backfill at a depth of about 1.5 metres is as a result of the water that was allowed to pond on top of the initial lift of sand-bentonite backfill during construction.

Survey measurements of the settlement plates located near the top of the sand-bentonite backfill have also been carried out. The north settlement plate is presently 2mm lower than its original position, with a maximum settlement of 9mm recorded in April, 1987. The west settlement plate has settled a total of 12mm since installation. Settlement of loose clay backfill material subjected to similar water conditions would be about 100 to 150mm.

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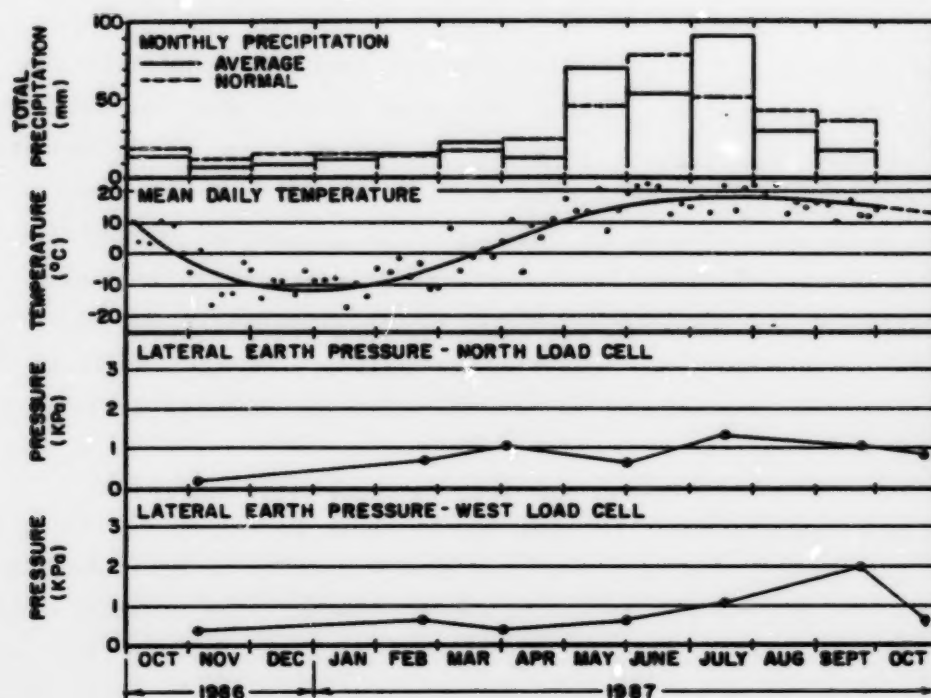


FIGURE 4 - MONITORING DATA FOR LATERAL EARTH PRESSURE

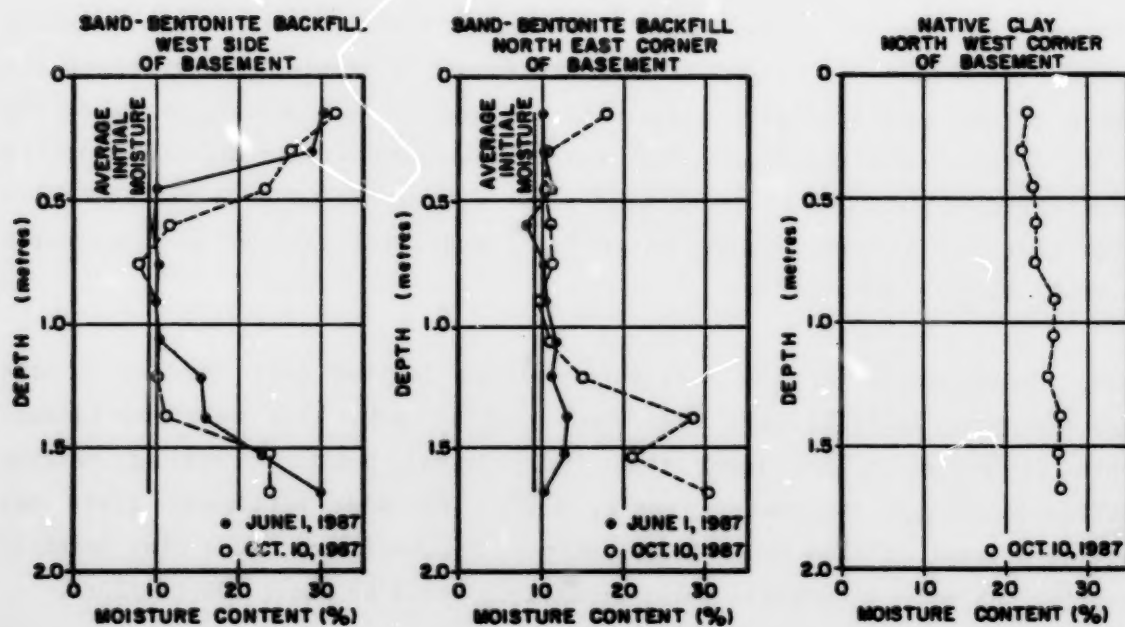


FIGURE 5 - MOISTURE CONTENT PROFILES

The lateral earth pressure (P) which will develop at any depth (H) against a rigid basement wall is given by the following expression:

$$P = KpgH \quad (1)$$

WHERE: P = total lateral earth pressure per unit wall area
 K = Lateral Earth Pressure Coefficient
 p = density of backfill,
 g = acceleration due to gravity and
 H = height of wall below grade

Based upon the geometry shown in Figure 2, the maximum recorded lateral earth pressure converts to a Coefficient of Earth Pressure of 0.16. By comparison, typical Coefficients of Earth Pressure At Rest for a loose sand vary from 0.5 (Wu, 1975), to 0.64 (Kazdi, 1975). and for compacted clay, hand tamped vary from 1.0 to 2.0 (Wu, 1975).

SECTION 4.0 COSTS OF FOUNDATION SYSTEM

The unit costs for the two types of foundation systems for residential construction were obtained from two basement contractors experienced with both types of basement construction in the City of Regina. A breakdown of the costs are shown in Tables 1 to 3, inclusive

TABLE 1 - COSTS OF CONVENTIONAL SHALLOW SPREAD FOOTING FOUNDATION
 SYSTEM WITH A GRADE SUPPORTED CONCRETE FLOOR SLAB

Conventional Spread Footing and Basement Walls

Labour and material to construct poured in place concrete footing and 2.45m high basement walls.	\$164.00/lineal metre
--	-----------------------

Concrete Floor Slab

Labour and material to construct a 100mm thick concrete slab-on-grade.	\$ 26.90/square metre
--	-----------------------

Backfill

Labour and material to place weeping tile system and native clay backfill around basement walls.	\$ 9.50/lineal metre
--	----------------------

TABLE 2 - COSTS OF BORED PILE FOUNDATION SYSTEM WITH A
SUSPENDED WOOD FLOOR AND SAND-BENTONITE BACKFILL

Pile Foundation System and Basement Walls

Labour and material to construct pile foundation
and 2.75m high basement walls. \$209.90/lineal metre

Suspended Wood Floor System

Labour and material to construct structural
wood floor, including any necessary centre
beams. \$ 30.10/square metre

Sand-Bentonite Backfill

Labour and material to place sand-bentonite
backfill \$ 24.30/lineal metre

Engineering

Design of foundation system, including
construction inspection. \$500.00

TABLE 3 - INCREMENTAL COSTS OF BORED PILE FOUNDATION WITH A
SUSPENDED WOOD FLOOR AND SAND-BENTONITE BACKFILL

Pile Foundation System

Underground foundation walls * supported
on a bored pile foundation system, and omitting
spread footing. \$45.90/lineal metre of wall

Suspended Wood Floor System

Substitute suspended wood floor for 100mm
thick concrete floor. \$ 3.20/square metre

Sand-Bentonite Backfill

Substitute sand-bentonite backfill
for clay backfill and omit weeping
tile and sump system. \$14.80/lineal metre of wall

Engineering

Design of foundation system
including construction inspection. \$500.00

* NOTE: Height of basement wall 0.3m higher than conventional wall.

For the house building under consideration, which had a basement area of 77 square metres, and a basement perimeter of 38 metres, the cost of the conventional shallow spread footing foundation system with a grade supported concrete slab is estimated to be \$8,644.00. The cost for the pile foundation system with a structural floor of wood construction and sand-bentonite backfill was \$11,717.00. The total incremental cost was \$3,053.00.

SECTION 5.0 DISCUSSION

- .1 Inspection of the house building at the time of construction indicated that the base of the excavation was dry. One year after completion of construction, a further inspection of the crawlspace area indicated that the foundation soils were relatively moist. In addition, the sand cover on top of the vapor barrier was moist. These factors, as well as the increase in moisture content of the base of the backfill from June, 1987, would indicate an increase in the subsoil moisture regime.
- .2 The sand-bentonite backfill placed around the perimeter of the house basement was intended to control the infiltration of surface water into the backfill and the subsoils. For this intent, the sand-bentonite mixture has proven to be successful as evidenced by the low moisture contents in the centre of the backfill, and no water problems in the basement area.
- .3 In some situations, surface water may by-pass the sand-bentonite backfill and infiltrate the clay subsoils through well developed secondary structure in the form of fissures and desiccation cracks in the undisturbed native clay soils. During periods of rainfall and/or lawn watering, rapid surface infiltration of water occurs into the clay subsoil resulting in an increase in the soil moisture regime. However, with the infiltration of water into the subsoil, the clay expands and the fissures and desiccation cracks will slowly close thereby effectively controlling the amount of water infiltrating into the subsoils. Thus, the amount of water which could enter the crawlspace by bypassing the sand-bentonite backfill is controlled by the clay soil and should not cause a water problem in the basement.

- .4 For the intent of minimizing the lateral earth pressure, the sand-bentonite backfill is, at present, successful. The maximum recorded total lateral earth pressure of 2 kPa is low in comparison to previously recorded pressures of 5.7 kPa for clay backfill (Hamilton, 1977). However, the moisture content profile in the sand-bentonite backfill is not at equilibrium. The moisture content at the depth of the total earth pressure cells (i.e. 900mm) has only increased by 1 to 3 percent, while the base and surface of the backfill has increased by over 20 percent. Thus, there is a potential that the lateral earth pressures will increase once moisture equilibrium has been achieved. The time frame for near moisture equilibrium will undoubtedly be in the order of a further 2 to 4 years since the sand-bentonite is a very effective barrier against water movement.
- .5 Inspection of the house building one year after completion of renovations has not revealed any evidence of heaving of the foundation system or distress in the suspended floor system. While the monitoring period is short in comparison to the lifespan of the house building, the same foundation system has been successfully applied to most commercial buildings in Regina over the past 30 years. The engineered bored pile foundation and suspended floor system is the most practical and economical solution to the problems associated with the performance of shallow foundations and grade supported concrete floor slabs in areas with shrink/swell clay type foundation soils.

SECTION 6.0 CONCLUSIONS TO THE STUDY

- .1 On the basis of this study, we recommend the bored pile foundation system with a suspended wood floor and sand-bentonite backfill in areas with shrink/swell type clay foundation soils.
- .2 The incremental costs of the bored pile foundation system with a suspended wood floor and sand-bentonite backfill, compared to the costs of a conventional shallow spread footing foundation system with a grade supported concrete floor slab, are nominal.

.3 On the basis of the writer's experience in areas with shrink/swell clay soils, the bored pile foundation system with a suspended wood floor and sand-bentonite backfill, also has the following advantages:

- i) improved long term performance of the building structure;
- ii) elimination of ongoing repairs and maintenance costs;
- iii) elimination of water problems in the basement. In addition, a suspended wood floor system, with the heat ducts installed beneath the floor, is a much superior floor system in as far as providing a more comfortable living area.

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APPENDIX A

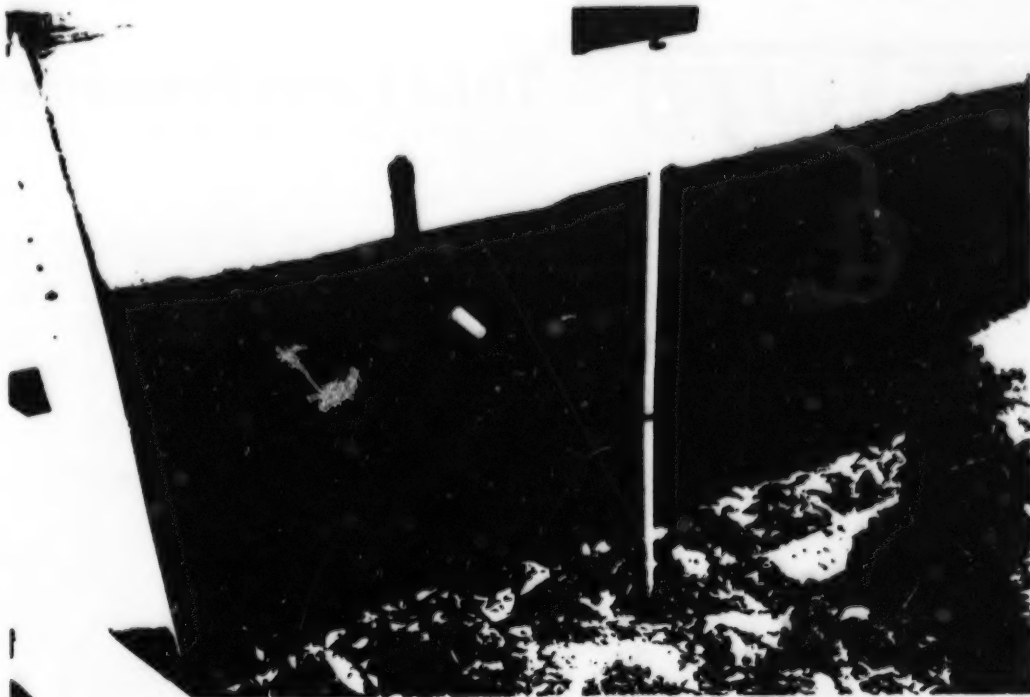


FIGURE A1 - PHOTOGRAPH OF MONITORING EQUIPMENT
ON NORTH SIDE OF HOUSE BASEMENT

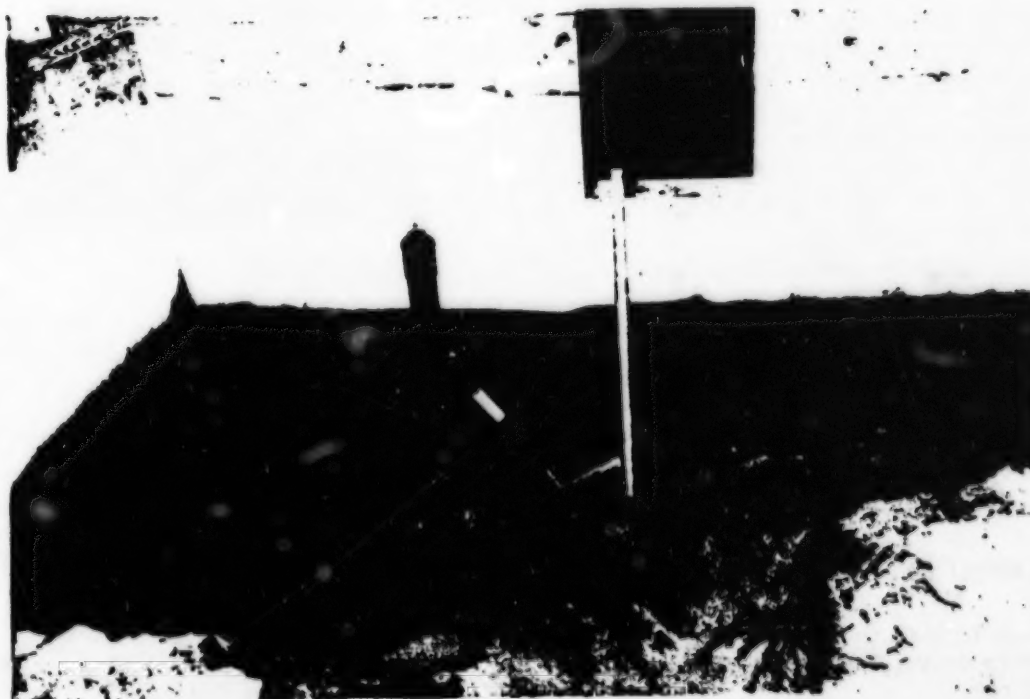


FIGURE A2 - PHOTOGRAPH OF SAND-BENTONITE BACKFILL
ON NORTH SIDE OF HOUSE BUILDING



Total Earth Pressure Cell

OPERATING PRINCIPLE:

Model TP-101 series Total Earth Pressure Cells are constructed from two circular stainless steel plates, heli-arc welded together around their periphery. The annular space between these plates is filled with an incompressible fluid. The cell is connected via a stainless tube to a transducer forming a closed hydraulic system. The stress is then converted to a signal and may be remotely read on a variety of portable readout units or data loggers.

FEATURES:

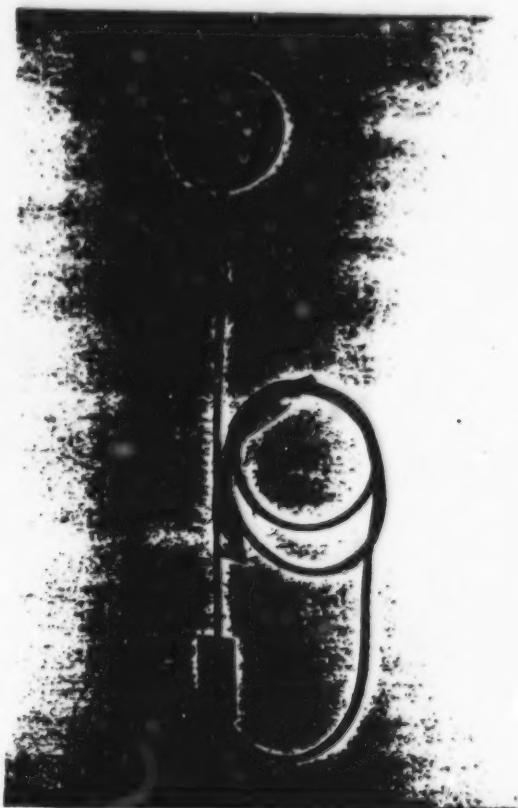
- ★ long term stability
- ★ high accuracy and sensitivity
- ★ constant monitoring capability
- ★ ease of data logging
- ★ either pneumatic, silicone strain gauge or vibrating wire transducers
- ★ due to the inherent high sensitivity it is not necessary to produce a large strain in the area monitored to measure stress
- ★ the transducer is located 30 in. (76.2 cm) from the cell to avoid any influence from the transducer housing
- ★ low cost with delivery from stock

ANCILLARY EQUIPMENT:

- ★ portable readout instruments
- ★ single channel data acquisition systems
- ★ multi channel data acquisition systems
- ★ readout terminal stations

CALIBRATION:

PETUR Total Earth Pressure Cells are calibrated prior to delivery. Graphs can be supplied with each cell.



APPLICATIONS:

Total Earth Pressure Cells are designed to measure stress acting on a plane surface and are typically installed in:

- ★ earth embankments
- ★ dams
- ★ foundation, retaining walls, and piles
- ★ against pipelines and culverts
- ★ against and under buildings
- ★ in railroad bases
- ★ beneath raft foundations
- ★ tunnel linings

SPECIFICATIONS:

MODEL	TP-101	TP-102	TP-103
TRANSDUCER TYPE	Pneumatic	Silicone Strain Gauge	Vibrating Wire
RANGE	0-2000 psi	0-5000 psi	0-5000 psi
OVERRANGE	2500 psi Maximum	150% FS	200% FS
ACCURACY	Equal to readout Gauge	0.1% FS	0.25% FS
RESOLUTION	Equal to readout Gauge	Infinite	0.1% FS
THERMAL EFFECT ON ZERO	Nil	0.1% per °C From 0-50°C	less than 0.05% FS
EXCITATION VOLTAGE	—	8 - 20 Unregulated	5v sq. Wave
SIGNAL OUTPUT	—	0-100 mV 0-1 v 4-20 mA 0-5 v	1200 - 2000 Hz Frequency
CONDUCTOR	2 x 3/16 O.D. Pneumatic Tubes	4 x #22 6 x #22 with Thermistor	2 x #22 4 x #22 with Thermistor
STANDARD CELL DIAMETER	9 inches	9 inches	9 inches
OPERATING TEMPERATURE	-40 to +40°C	-40 to +120°C	-29 to +65°C

Manufactured By:

PETUR INSTRUMENTS LTD.
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Port Coquitlam, B.C. Canada V3C 4K9
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Represented By:

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